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ABSTRACT

This study investigated five ability tests related to the water-jug problem. Previous analyses identified two processes used during solution: means-ends analysis and memory of visited states. Subjects were 240 undergraduate psychology students. A real-time computer system presented the problem and recorded responses. Ability tests were paper and pencil. Within-between analysis found significant effects of problem and pre- posttesting but not of sex or instructions. Alternate additions was the only test correlated with the water-jug measure across instructions. Subjects who could generate several possible combinations of numbers performed more efficiently. (Author/MN)

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Relationship of Selected Abilities to Problem Solving Performance

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This study is one in a series of experiments involving water-jug problems (Harmel,1977). The study investigated five ability tests related to the nature of the task and instructional manipulations. Ability tests were alternate additions, digit span memory, mental rotations, imagery control, and imagery vividness.

Characteristics of the task determine in large part the manner in which a person approaches and solves that task, and the abilities used during solution. Greeno(1977) classified three types of problems. The present study used a water-jug problem which is a transformation problem. This is a state-space problem; with every move the problem reaches a different state. The present water-jug problem differs from that of Luchins; the problem requires a larger number of steps to solution, and no algorithm can be induced with one problem presentation. Recent theoretical analysis (Atwood & Polson,1976; Atwood,1976) using water-jug problems have isolated two processes. These are means-ends analysis and a heuristic that avoids previously visited states. Means-ends analysis computes an evaluation for each state; this evaluation is the numerical difference between current and goal contents of the two critical jugs. Atwood and Polson hypothesize that in selecting a move operation, the subject chooses the one which leads to a state with a lower evaluation. The water-jug problem is structured so that some moves on the solution path violate the means-ends move selection heuristic; subjects have difficulty at these points and choose a state not previously visited. The success of the solver depends upon his skill in applying means-ends analysis and in recalling previously visited states.

Because of the memory processes used during solution, imagery instructions were included as a variable in the task. Subjects were instructed to construct a mental image, or picture, of the water in the jugs and the results of any pouring operation. Imagery instructions have previously been found to facilitate performance in studies of verbal learning and memory (Paivio,1971), and on other types of problems (Gurova,1969; Bejat,1972). Imagery controllability has been found to be correlated with a geometric problem solving task (Snyder,1972). The present study investigated the generalizability of imagery to a problem with a high numeric component.

Means-ends analysis during solution of the water-jug problem requires manipulation and comparison of numbers. Guilford's(1967) test, Alternate Additions, was chosen to test the subject's numerical manipulations ability. The test is also a measure of Divergent Production, or the subject's readiness to change direction in thinking or to modify information.

The digit span test is a measure of short term memory. This ability may be used during processing the water-jug task; more moves may be remembered and facilitation of solution may occur.

The imagery abilities included were imagery control, imagery vividness, and mental rotation. The subject who has high imagery capability may be able to process more information at one time, and remember more previously visited states during water-jug problem solution.

METHODS

Subjects There were 240 undergraduate subjects from the psychology subject pool.

Water-Jug Problem Complex water-jug problems were chosen for the experiment. There were three jugs: A, B, C. The within-between analysis was performed on a 4-path problem, jug sizes (20,12,9). There were two paths to each of two goals, G1(14,6,0) and G2(15,5,0). In the beginning, or start state, jug

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A was full and jugs B and C were empty. The subject was to perform pouring operations, in accordance with the three rules, until the goal was reached. There were 27 possible states to be moved to. The particular pouring operation chosen by the subject determined which state he would move to. The start state and the four states at the top of each path are top states. From each state on the four paths, the subject could move forward towards the goal, backwards to the just occupied state, or make an irreversible looping move back to one of the five top states. Looping moves to top states is a measure of problem solving efficiency; subjects who make many looping moves are not using their memory of previously occupied states, are miscalculating the results of moves, or are moving randomly.

Ability Tests The alternate additions test (ADD) was in two parts, each took three minutes. The subject was given a series of numbers to add to a particular sum. The score was the number of correct responses.

The digit span memory test was experimenter-developed and recorded on magnetic tape. It was similar to the Weschler Digit Span Forward. There were seven series of numbers (3 to 9 digits) with two trials per series. The measure was total number correct (DIG).

The Gordon Imagery Control Test (Richardson,1969) is 12 questions asking if the subject could perform a specific imaging task. He was to answer 'yes', 'no', or 'unsure'. The test was untimed. The total score (IT) was computed by multiplying each yes by 2, unsure by 1, and no by 0.

The visual image portion of the shortened form of the Betts Vividness of Imagery was used (Richardson,1969). There were five images to be rated on a 7-point scale. The test was untimed.

A version of the Shepard and Metzler(1971) mental rotation task was adapted by Vandenberg(1971). A drawing of a three-dimensional block arrangement was to be matched, two of four drawings were identical but in a rotated position. The test consisted of two parts, ten items per part and five items per page. Subjects were given three minutes for each part. The score was total number of correct items attempted (RT).

Design The design is 2x2x2x2x2 with equal n's in each cell. There was a pre-test or post test, and sex was a variable. The problems were G1(14,6,0) and G2(15,5,0). There was a graph of the jugs present or not present. Subjects were instructed to image or calculate the results of the move.

RESULTS

A within-between analysis was performed. The between group variables were problem type, graph presence, imagery-calculation instructions, sex, and test. for the between group analysis there was a significant effect of problem type, $F(1,128)=22.66, p<.001$, and of test, $F(1,128)=3.87, p<.01$. There were no other main effects and no interactions. The within subject variable was the number of looping moves to the five top states. There was a significant over-all effect, $F(4,512)=77.21, p<.001$. There was a significant interaction of looping move pattern and problem type, $F(4,512)=9.07, p<.001$. There were two four-way interactions, probably due to the large subject variance.

The next analyses intercorrelated the water-jug measure looping moves to top states with the ability test measures, and with sex and test. The test of significance was two-tailed. Test was significantly correlated with moves to top states (post test subjects made fewer moves). Sex was significantly correlated with mental rotation(RT) and alternate additions(ADD) (males>females). Imagery control(IT) was significantly correlated with imagery vividness(IV) (high control r high vivid). ADD was significantly

correlated with RT and digit memory (high r high), and with moves to top states (high ability r fewer moves).

CONCLUSIONS

The difference in problem difficulty was expected; problem G2(15,5,0) has more possibilities of returning to the top states, and is returned to non-goal top states. The pre-test subjects performed worse on the water-jug task than subjects given the tests after the task. There was no difference in the process operators chosen, both groups returned similarly to each of the top states. After forty minutes of testing, the subjects seem to pay less close attention to the water-jug task, choosing a greater number of random moves.

In the Atwood and Polson(1976) model, move choices depend upon the subjects' recognition of previously made moves. The correlations between the digit span memory test and the water-jug measure was practically zero. One reason for the lack of relationship may be differences between the contribution of long and short term memory to the task. Atwood and Polson's model supposes that the move information enters and is retrieved from long term memory whereas the digit memory task is supposed to be a short term memory task.

There were no over-all correlations with the imagery measures and the water-jug task. However, in other analyses, under imagery instructions only, subjects with nigh imagery control performed better on the water-jug task. Subjects with high imagery control also have higher vividness. However, neither are correlated with mental rotation scores. Although the subjects in Shepard and Metzler's(1971) study reported they used mental imagery on the mental rotation task, this ability may not be the same as that measured by the Gordon or Betts tests. Apparently Vandenberg's(1971) version of the mental rotation task has small effect on solving a water-jug problem by naive solvers. The relationship between alternate additions and mental rotations and digit span memory may be attributed to the time pressures of the tests rather than one underlying ability.

Alternate additions performance was related to water-jug solution: those subjects who were able to produce several correct additions of a set of numbers returned to start states less often and solved the water-jug problem in fewer moves. The subject's speed and facility of calculation will effect solution. If subjects err in calculating, they may loop back and take several more legal moves before reaching solution. Also, the subject may make use of Divergent Productions. According to the model, subjects generate possible moves and choose the best move. Subjects who are able to generate numerous possibilities do well on the water-jug task.

The implications are that the teacher must analyze task and student characteristics before giving problem solving instructions. The water-jug task has such a nigh numerical component that any imagery processing is masked. (However, the present subjects had not had extensive imagery training.) This study indicates that if students can rapidly generate and manipulate numerical information, then performance on a water-jug problem solving task is facilitated. Students could be taught to generate several possible moves, and improve their use of numerical manipulations.

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